Chapter 1

TD-SCDMA HSDPA/HSUPA: Principles, Technologies, and Performance

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Contents

1.1 Overview

Jointly developed by the China Academy of Telecommunications Technology (CATT) and Siemens Ltd., Time Division Duplex-Synchronous Code Division Multiple Access (TD-SCDMA) is one of the IMT-2000 standards that was approved by the International Telecommunication Union (ITU). At the time when the 29th Olympic Games were held in Beijing, the performance of the China Communications Standards Association (CCSA) N-frequency TD-SCDMA DCH (Dedicated Channel)-based services was well tested in the commercial network operated by the China Mobile Communication Corporation (CMCC). Nowadays, with the ever-increasing demand for the higher data rates and aiming at providing various multimedia services, TD-SCDMA networks are evolving toward an enhanced version, TD-SCDMA HSDPA/HSUPA (High Speed Downlink/Uplink Packet Access).

This chapter aims to provide an overview of the evolution of TD-SCDMA networks to the HSPA version, including key techniques, channel processing, and operation principles. Performance evaluations are also provided to aid in evaluating the capability of TD-SCDMA HSPA.

1.2 Introduction

As the basic 3G (the 3rd Generation mobile communication system) choice in China [1, 2], TD-SCDMA has been widely accepted and adopted. The performance of the CCSA N-frequency TD-SCDMA DCH-based services has been well tested in both trials and commercial networks, especially during

the time of the 29th Olympic Games held in Beijing in 2008. It was shown that DCH-based TD-SCDMA is able to reliably provide both voice service and packet services.

Nowadays, with the ever-increasing demand on the data transmission rates and the various multimedia services, TD-SCDMA networks are evolving toward TD-SCDMA HSDPA/HSUPA. Single-frequency TD-SCDMA HSDPA was introduced in the 3rd Generation Partnership Project (3GPP) in the R5 (Release 5) version as the downlink evolution of TD-SCDMA networks. Multi-frequency TD-SCDMA HSDPA, introduced by the CCSA, is the enhanced version of the 3GPP single-frequency TD-SCDMA HSDPA; it adopts multi-frequency to improve system performance. It offers backward-compatible upgrades to both former N-frequency TD-SCDMA networks and single-frequency TD-SCDMA HSDPA systems. In 2006, the 3GPP made an effort to standardize the uplink evolution of TD-SCDMA networks. Released as the 3GPP R6 version, TD-SCDMA HSUPA is believed to be able to significantly enhance the system uplink capacity. To offer the backward-compatible upgrade to both the N-frequency TD-SCDMA and multi-frequency TD-SCDMA HSDPA, the CCSA started the standardization work of multi-frequency TD-SCDMA HSUPA in August 2007. Now, in both the CCSA and 3GPP, multi-frequency TD-SCDMA HSDPA/HSUPA have been specified. This chapter introduces the key concepts of TD-SCDMA HSDPA/HSUPA networks, including key techniques, protocols, channel processing, and principles of operation. Performance evaluations are also provided to aid in evaluating the key aspects of TD-SCDMA HSPA.

1.3 What Is TD-SCDMA?

Before delving into TD-SCDMA HSDPA/HSUPA, we first provide a short review of TD-SCDMA systems. Jointly developed by CATT and Siemens Ltd., TD-SCDMA is one of the IMT-2000 standards approved by the ITU. Let us begin with TD-SCDMA. The “TD” part of the term has two meanings:

1. It is based on TDD modes, which brings many advantages, such as easily accommodating asymmetrical traffic and high correlation between the downlink (DL) and uplink (UL) channel.
2. TDD operation also makes full use of the asymmetrical frequency resource and makes it very flexible in frequency band occupation. It uses combined TDMA (Time Division Multiple Access) and CDMA (Code Division Multiple Access) for multiple access. The signal is separated in both the time domain and the code domain [3].

The “S” denotes synchronous operation. Such a characteristic brings not only the relative low interference operation, but also the cost-efficient operation of the system.

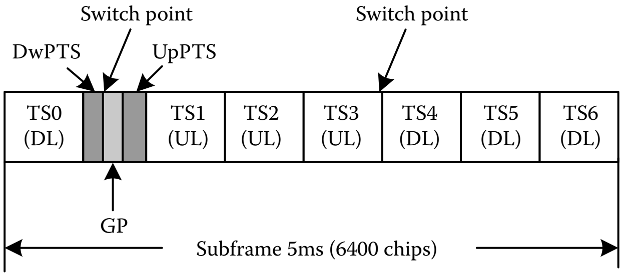

Figure 1.1 Sub-frame structure of TD-SCDMA (symmetric configuration).

Figure 1.1 shows the TD-SCDMA frame structure. The TDMA frame has a duration of 10 ms and is divided into two subframes of 5 ms each. The frame structure for each subframe in the 10-ms frame length is the same. Time slots #0 through 6 make up the traffic time slot, and each contains 864 chips. The DwPTS and UpPTS are the downlink and uplink pilot time slots, containing 96 and 160 chips, respectively, and are designed for downlink and uplink synchronization purposes. GP is the guard period for TDD operation, containing 96 chips. The entire 5-ms sub-frame contains 6,400 chips, indicating that the chip rate of TD-SCDMA is 1.28 Mchips/s. The operation band for TD-SCDMA is 1.6 MHz. Compared to wideband CDMA (WCDMA) [4], TD-SCDMA is a narrowband system.

Among these seven traffic time slots, time slot #0 is always allocated for DL (downlink) while time slot #1 is always allocated for UL (uplink). The time slots for the UL and the DL are separated by switching points. Between the downlink time slots and the uplink time slots, the special period is the switching point to separate the uplink and downlink. In each subframe of 5 ms, there are two switching points (UL to DL and vice versa). Using the above frame structure, TD-SCDMA can operate on both symmetric and asymmetric mode by properly configuring the number of DL and UL time slots. In any configuration, at least one time slot (time slot #0) must be allocated for DL, and at least one time slot must be allocated for UL (time slot #1). In a multi-frequency cell, the traffic time slots allocated for UL and DL pair(s) for one UE should be on the same carrier.

Due to the above characteristics, TD-SCDMA is able to adopt various advanced techniques to enhance system performance and boost system capacity. The TDD mode makes the UL channel and the DL channel highly correlated. Thus, channel estimation based on the UL channel can be used for the DL if the interval between UL reception and DL transmission is less than the channel coherent time. This provides a good condition for the implementation of a smart antenna [5–8], which can boost the signal strength while compressing or nulling the interference. For low chip rate

and narrowband operation, advanced receivers can be implemented. TD-SCDMA adopts multi-user detection [9] to combat the various interferences that the CDMA system holds, that is, inter-symbol interference (ISI) and multiple access interference (MAI). The synchronous operation facilitates the operation of baton handover, which smoothes the interruption experience when users hand over from one cell to another. The combination of TDMA and CDMA enables the adoption of dynamic channel allocation (DCA) [10], which can adjust the load of different time slots, achieving load balancing at any time slot. Due to space limitations, we end here with the introduction of TD-SCDMA systems. Interested readers can refer to [2, 11–19] for the details of TD-SCDMA systems, including operation protocols [11, 13–19], key techniques (see [2] and the reference therein), resource management [12], etc.

1.4 TD-SCDMA HSDPA

TD-SCDMA HSDPA, which can be recognized as the 3.5G evolution of the TD-SCDMA system, aims to improve the downlink capacity and throughput of the TD-SCDMA system. By adopting advanced techniques, such as adaptive modulation and coding (AMC), Hybrid Automatic Repeat reQuest (Hybrid ARQ, HARQ) and fast packet scheduling, TD-SCDMA HSDPA can accommodate both real-time and non-real-time services with quality-of-service (QoS) guarantee. The peak data rate for TD-SCDMA HSDPA is 2.8 Mbps adopting five time slots with full code utilization, 16QAM (quadrature amplitude modulation), and non-multiple-input, multiple-output (MIMO) operation. In this section we introduce the TD-SCDMA HSDPA system, including its concepts and principles, key techniques, transport and control channels, and the related operation principles.

1.4.1 General Concepts and System Architecture

Figure 1.2 shows the system architecture of TD-SCDMA HSDPA. The downlink data originates from a multimedia service server, such as a Web server or streaming media server, and then passes through the core networks (CNs) and arrives at the radio network controller (RNC). After the data is processed by each layer residing at the RNC—namely, the PDCP/RLC/MAC-d (medium access control-dedicated) layer—the data is encapsulated into MAC-d PDUs (Protocol Data Units), which are further routed to the specific base station to which the target user belongs. The MAC-d PDUs are further packed into MAC-hs (high speed) PDUs at the base station and then sent via the TD-SCDMA HSDPA air interface. When the data correctly arrives at the user terminal, each layer at the user terminal does opposite operations. The new entity introduced into TD-SCDMA HSDPA is

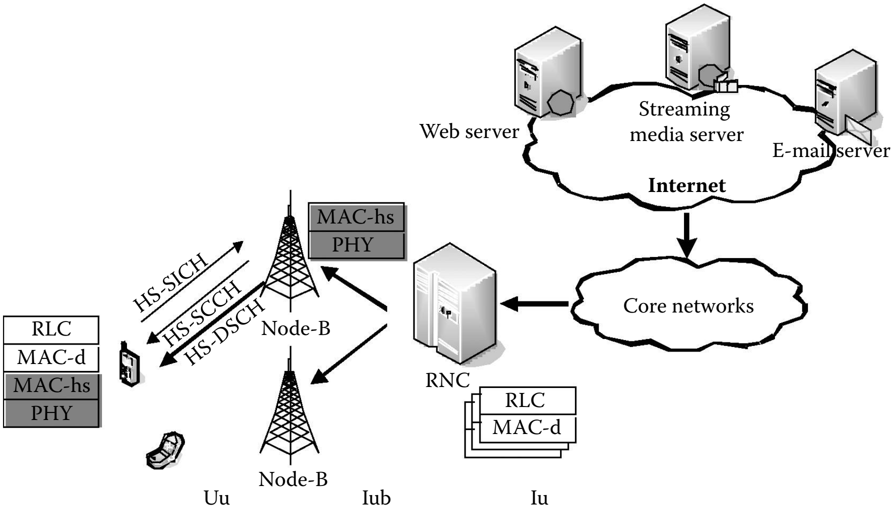

Figure 1.2 TD-SCDMA HSDPA system architecture.

the MAC-hs sublayer, which is in charge of user/packet/PDU scheduling, transmit format selection, and HARQ-related processing. Due to the HARQ retransmission operation, packets arriving at the MAC layer of Node-B (a call for base station in 3G enviroments) are typically out of sequence. Another key function of MAC-hs is the in-sequence delivery of the MAC-d PDU to the MAC-d layer. There are three HSDPA-related channels: (1) High-Speed Downlink Shared Channel (HS-DSCH), (2) High-Speed Shared Control Channel (HS-SCCH), and (3) High-Speed Shared Information Channel (HS-SICH). The HS-DSCH is the transport channel; it is used to carry the HSDPA-related traffic data. HS-SCCH and HS-SICH are physical control channels designed for transmitting HSDPA signaling.

1.4.2 Key Techniques

1.4.2.1 Link Adaptation

The benefits of adapting the transmission parameters in a wireless system to the changing channel conditions are well known. In fact, fast power control is an example of a technique implemented to enable reliable communications while simultaneously improving the system capacity. The process of modifying the transmission parameters to compensate for variations in channel conditions is known as *link adaptation*.

One technique that falls into the category of link adaptation is AMC [20]. The principle of AMC is to change the modulation and coding format in accordance with variations in the channel conditions. The channel conditions can be estimated, for example, based on feedback from the receiver.

In a system with AMC, users in favorable positions (e.g., users close to the cell site) are typically assigned higher-order modulation with higher code rates (e.g., 64QAM with $R = 3/4$ Turbo codes), while users in unfavorable positions (e.g., users close to the cell boundary) are assigned lower-order modulation with lower code rates [e.g., QPSK (quadrature phase-shift keying) with $R = 1/2$ Turbo codes]. The main benefits of AMC are (1) higher data rates being available for users in favorable positions, which, in turn, increases the average throughput of the cell, and (2) reduced interference variation due to link adaptation, based on variations in the modulation/coding scheme instead of variations in transmit power.

In TD-SCDMA HSDPA, the user measures the downlink channel quality and sends the channel quality indicator (CQI) on HS-SICH. After decoding the CQI information, the AMC entity at the base station decides which modulation and coding scheme (MCS) should be used when it performs the next transmission to this user. The chosen MCS information, together with the allocated resource information, is notified on HS-SCCH. Due to the interference fluctuation brought by smart antennas, the MCS selection accuracy is much lower in TD-SCDMA HSDPA than in WCDMA HSDPA [21, 22]. It has a negative impact on the performance of TD-SCDMA HSDPA.

ARQ is another type of link adaptation technique. ARQ compensates for channel variations in an implicit way via retransmissions. Hybrid ARQ with soft combining allows the rapid retransmission of erroneous transmitted packets at the MAC layer. It is able to reduce the requirement of RLC layer retransmission and the overall delay; thus, it can improve the QoS of various services. Prior to decoding, the base station combines information from the initial transmission with that of later retransmissions. This is generally known as *soft combining* and is able to increase the successful decoding probability. Incremental redundancy (IR) is used as the basis for the Hybrid ARQ operation, and either the same or different versions of parity bits can be sent in the possible retransmissions. If the same parity bits are sent, the well-known Chase Combining is used to combine different transmissions, and thus the energy gain can be obtained. Otherwise, if retransmissions contain different parity bits, additional coding gain can also be obtained. If the code rate of initial transmission is high, the coding gain provided by retransmitted parity bits is important; otherwise, if initial code rate is already low, the energy gain is more obvious. With the fast retransmission ability and combing gain brought by Hybrid ARQ, the initial transmission can be performed in relatively higher data rate and target at higher error ratio but with the same power as that of lower data rate targeting lower error ratio. The required lower error ratio can be achieved by subsequent retransmissions. Such operation can obtain the early termination gain (ET gain). Such gain comes from the fact that retransmissions can bring time diversity gain. The shorter transmission time interval (TTI) and the larger allowed transmissions will result in larger gain exploitation. Therefore, the

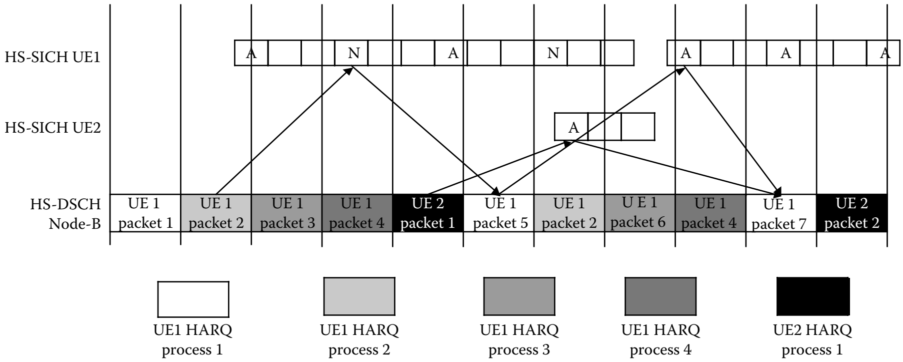

Figure 1.3 N parallel stop-and-wait Hybrid ARQ processes.

delay-tolerant services, such as file-uploading and e-mail, can be operated in such a way.

In TD-SCDMA HSDPA, N parallel stop-and-wait Hybrid ARQ processes are adopted to facilitate ARQ management and allow continuous transmitting. In N parallel stop-and-wait Hybrid ARQ, data transmitted over HS-DSCH is associated with one Hybrid ARQ process. Initial transmission and possible retransmission(s) are restricted to perform on the same process. Figure 1.3 illustrates the operation principle of $N = 4$ parallel stop-and-wait in TD-SCDMA HSDPA.

1.4.2.2 Fast Packet and User Scheduling

When serving packet services, resource sharing among users is believed to be more efficient than dedicating to a certain user. Resource sharing is enabled in TD-SCDMA HSDPA via the shared channel HS-DSCH. Here, scheduling is an important function in determining when, at what resource, and at what rate the packets transmit to a certain user. Combined with AMC, scheduling in TD-SCDMA HSDPA takes advantage of fat-pipe multiplexing, that is, transmitting as many packets as possible to a certain user when it has relatively good channel quality. Different from TD-SCDMA, in TD-SCDMA HSDPA, the scheduling entity resides in the base station, which enables the scheduler to quickly adapt to both the interference and user channel variations.

The scheduling policy is an implementation issue and is flexible based on the system requirements. In general, greedy methods can improve the overall system throughput. Also, other scheduling methods may take the user fairness, traffic priority, service QoS, and operator's operating strategy into consideration [23]. Examples are the PF (Proportional Fair) scheduling [24] method in providing non-real-time services, while EXP (Exponential Rule) and M-LWDF (Modified Largest Weighted Delay First Rule)

[25] are believed to be suitable for serving the real-time services. Under the mixed services scenario (e.g., simultaneously serving VoIP (Voice over Internet Protocol) and other background services), in order to guarantee different QoS requirements of different services, a differential scheduling mechanism is required [26].

1.4.3 Multi-frequency TD-SCDMA HSDPA

Because TD-SCDMA is a narrowband system, the peak data rate provided by TD-SCDMA HSDPA is limited. To overcome this drawback, multi-frequency operation for TD-SCDMA HSDPA is adopted [27]. For multi-frequency operation, multiple 1.6-MHz frequency bands are combined and operated together. As shown in Figure 1.4, in multi-frequency TD-SCDMA

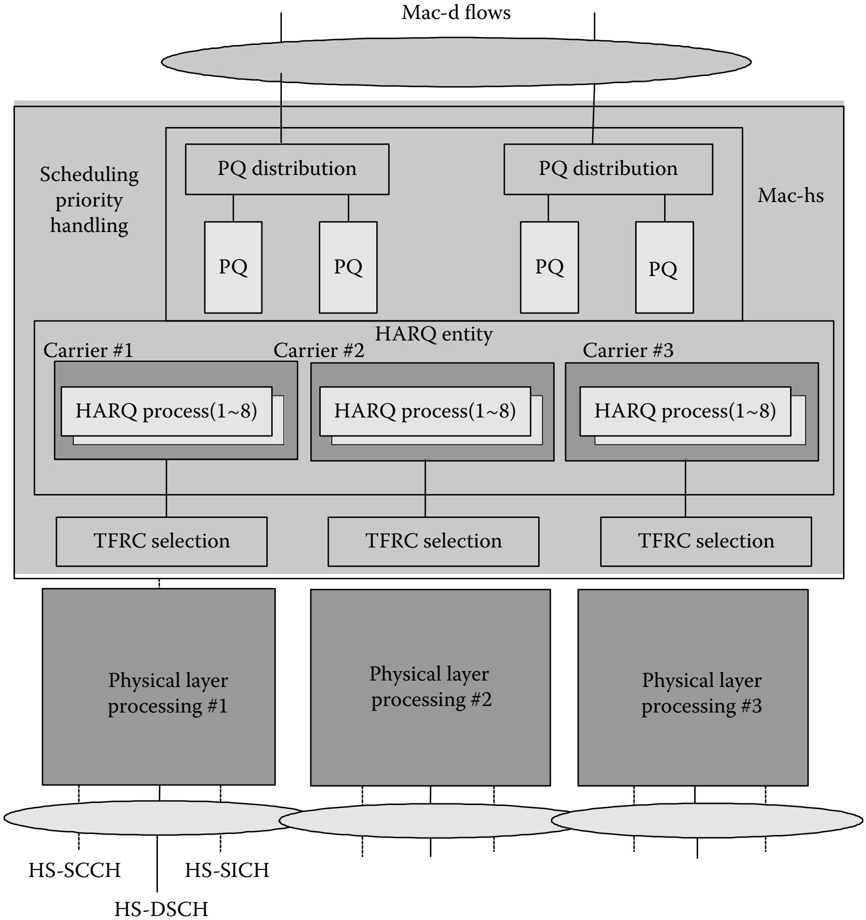

Figure 1.4 Data processing in multi-frequency TD-SCDMA HSDPA.

HSDPA, there are multiple sets of HSDPA-related channels—that is, multiple {HS-DSCH, HS-SCCH, HS-SICH} sets, one set for each carrier. Scheduling and resource allocation should be performed over all carriers simultaneously based on the CQI information on each carrier. One UE (user equipment) may or may not receive multiple data streams from multiple carriers. Carrier data distribution is performed at the MAC layer right above the Hybrid ARQ entity. Below the Hybrid ARQ entity, there are multiple data flows and one for each carrier. TFRC (transmit format and resource combination) selection should be performed for each carrier separately.

1.4.4 TD-SCDMA HSDPA Channels

As discussed above, for the operation of TD-SCDMA HSDPA, three additional channels are introduced: one transport channel (HS-DSCH) and two control channels (HS-SICH and HS-SCCH). HS-DSCH is used for carrying the TD-SCDMA HSDPA-related data information. HS-SCCH is used for downlink signaling purposes, indicating the resource position, conveying the Hybrid ARQ-related parameters, etc. HS-SICH is used for the feedback of channel quality information and the information of correctly decoding or not (ACK/NACK). In this section, detailed processing procedures for these channels are introduced. Using these processing procedures, the key techniques introduced above are incorporated. Before going into the detailed channel processing procedure, we first introduce the timing and association relationship between the TD-SCDMA HSDPA-related transport and control channels, that is, the timing and association between HS-DSCH and HS-SCCH, and between HS-SCCH and HS-SICH. These associations and timing determine the right operation of TD-SCDMA HSDPA.

1.4.4.1 Association and Timing

1.4.4.1.1 HS-DSCH and HS-SCCH

The transport channel HS-DSCH can be associated with a number of downlink control channels HS-SCCHs. In a multi-frequency HS-DSCH cell, HS-DSCH may be mapped on HS-PDSCHs (the physical layer channel conveying the HS-DSCH data information) on one or more carriers for UE supporting multi-carrier HS-DSCH reception. HS-DSCH transmission on each carrier is associated with an HS-SCCH subset, and the number of HS-SCCHs in one HS-SCCH subset can range from a minimum of one to a maximum of four. All the HS-SCCH subsets for one UE constitute an HS-SCCH set. For UE not supporting multi-carrier HS-DSCH reception, only one HS-SCCH subset is allocated. All relevant Layer-1 control information is transmitted in the associated HS-SCCH; that is, the HS-PDSCH does not carry any Layer-1 control information, which is used for conveying Layer-2 (MAC) information only.

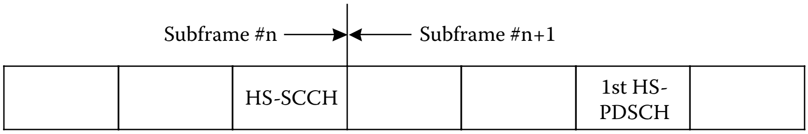

Figure 1.5 Timing for HS-SCCH and HS-DSCH (DwPTS and UpPTS not included).

The HS-DSCH-related time slot information that is carried on the HS-SCCH refers to the next valid HS-PDSCH allocation, which is given by the following limitations: The indicated HS-PDSCH is on the subframe next to the HS-SCCH carrying the HS-DSCH related information. The HS-DSCH-related time slot information does not refer to two subsequent subframes, but always refers to the following subframe, as illustrated in Figure 1.5. In case of multi-carrier HS-DSCH reception, the timing for HS-DSCH transmission on each carrier and its associated HS-SCCH applies the same rule.

1.4.4.1.2 HS-SCCH and HS-SICH

The HS-SCCH is always associated with one HS-SICH, carrying the ACK/NACK and CQI. The association between the HS-SCCH in DL and HS-SICH in UL is predefined by higher layers and is common for all UEs.

The UE with a dedicated UE identity transmits the HS-DSCH related ACK/NACK on the next available associated HS-SICH with the following limitation: There shall be an offset of nine time slots between the last allocated HS-PDSCH and the HS-SICH for the given UE. DwPTS and UpPTS are not taken into account in this limitation. Hence, the HS-SICH transmission is always made in the next but one subframe, following the HS-PDSCH transmission, as illustrated in Figure 1.6. In the case of multi-carrier HS-DSCH reception, the timing for HS-DSCH transmission on each carrier and its related HS-SICH applies the same rule.

The timing between the HS-SCCH and the HS-SICH for the given UE is illustrated in Figure 1.7. The UE transmits the HS-SCCH-related ACK on the next available, associated HS-SICH with the following limitation: There shall be an offset of 14 time slots between the HS-SCCH and the HS-SICH

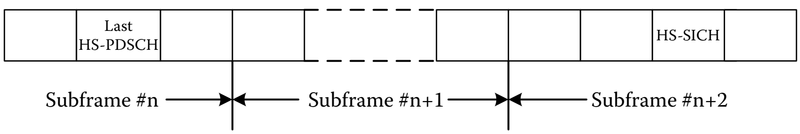

Figure 1.6 Timing for HS-DSCH and HS-SICH (DwPTS and UpPTS not included).

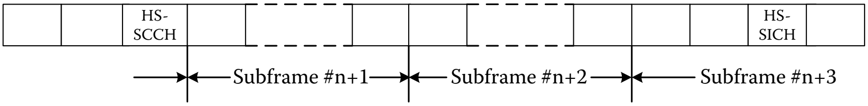

Figure 1.7 Timing for HS-SCCH and HS-SICH (DwPTS and UpPTS not included).

for the given UE. DwPTS and UpPTS shall not be taken into account in this limitation.

1.4.4.2 Channel Processing

1.4.4.2.1 HS-DSCH

Figure 1.8 illustrates the overall procedure of processing for HS-DSCH. Data arrives at the coding unit in the form of one transport block once every TTI, which is 5 ms for TD-SCDMA HSDPA. The entire processing procedure includes the following steps:

1. A CRC (cyclic redundancy check) of 24 bits to each transport block
2. Code block segmentation
3. Channel coding
4. Hybrid ARQ processing

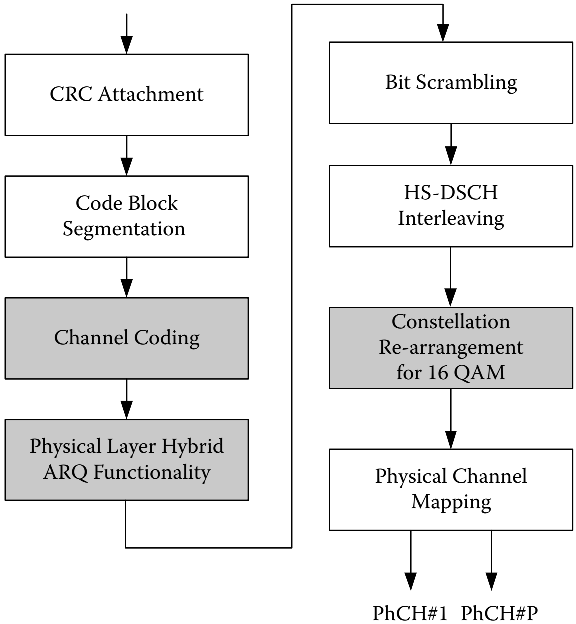

Figure 1.8 Physical layer processing for HS-DSCH.

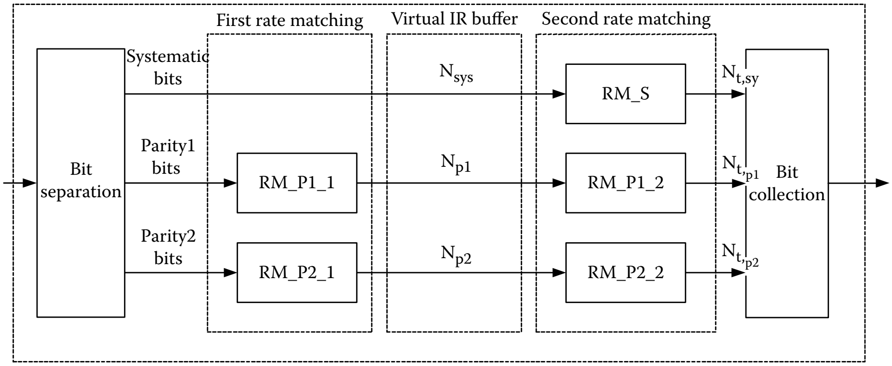

Figure 1.9 HS-DSCH Hybrid ARQ functionality.

5. Bit scrambling
6. Interleaving
7. Constellation re-arrangement for 16QAM
8. Mapping to physical channels

As WCDMA HSDPA, only Turbo code with rate 1/3 is used for the HS-DSCH channel. This was motivated by the fact that Turbo coding outperforms convolution coding otherwise expected with the very small data rates. Additional new issues for HS-DSCH processing include the handling of 16QAM constellation rearrangement and Hybrid ARQ processing on the physical layer for the HS-DSCH.

Figure 1.9 shows the functionality of Hybrid ARQ. This functionality matches the number of bits at the output of the channel coder to the total number of bits of the HS-PDSCH set to which the HS-DSCH is mapped. The Hybrid ARQ functionality is controlled by the redundancy version (RV) parameters. The exact set of bits at the output of the Hybrid ARQ functionality depends on the number of input bits, the number of output bits, and the RV parameters. The Hybrid ARQ functionality consists of two rate-matching stages and a virtual buffer, as shown in Figure 1.9. The first rate-matching stage matches the number of input bits to the virtual IR buffer. Note that if the number of input bits does not exceed the virtual IR buffering capability, the first rate-matching stage is transparent. The second rate-matching stage matches the number of bits after the first rate-matching stage to the number of physical channel bits available in the HS-PDSCH set in the TTI.

For 16QAM modulation, there is the specific function of constellation rearrangement, which maps the bits to different symbols depending on the transmission numbers. This is beneficial because, as with 16QAM, all the symbols do not have equal error probability in the constellation. The reason is that different symbols have different numbers of neighboring symbols,

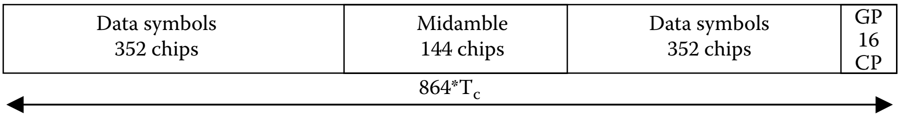

Figure 1.10 Burst type for HS-SICH (T_c is chip duration, midamble is training sequence).

which places the symbols closer to the axis, with a greater number of neighboring symbols more likely to be decoded incorrectly than the other symbols further away from the axis.

1.4.4.2.2 HS-SICH

HS-SICH is used to carry the CQI and ACK/NACK information. The following burst type is used for HS-SICH. HS-SICH will carry the transmit power control (TPC) and Synchronozation Shift (SS) bits for power control of HS-SCCH and for synchronous purposes, respectively. The spreading factor is 16 for HS-SICH. Thus, HS-SICH will carry 44 information bits in the first data field and 40 information bits plus 2 bits TPC and 2 bits SS in the second data field (see Figure 1.10).

The physical layer processing for HS-SICH is shown in Figure 1.11. The following information is transmitted by means of the HS-SICH:

1. Recommended modulation format (RMF) (1 bit), which is used by UE to recommend its favorable modulation format, namely, QPSK (0 indicates) or 16QAM (1 indicates). The RMF is repetition coded to 16 bits.
2. Recommended transport-block size (RTBS) (6 bits). UE uses this field to recommend the data amount that is preferred to be received by UE in the next TTI. The 6 bits of the RTBS field are coded to 32 bits using a (32, 6) first-order Reed-Muller code.
3. Hybrid ARQ information ACK/NACK (1 bit), with the value 0 indicating NACK and 1 indicating ACK. For the coding of this field, the repetition code is adopted. The one indication bit is repeated to 36 bits.

All these bits (84 bits) are then multiplexed and interleaved before mapping and being transmitted on the code channel.

1.4.4.2.3 HS-SCCH

HS-SCCH is used for the transmission of HS-DSCH-related control information. The following burst type is used for HS-SCCH. HS-SCCH contains two code channels (HS-SCCH1 and HS-SCCH2). HS-SCCH1 will carry the TPC and SS bits for power control of HS-SICH and synchronization purposes, respectively. The spreading factor is 16 for HS-SCCH. Thus, HS-SCCH1 will

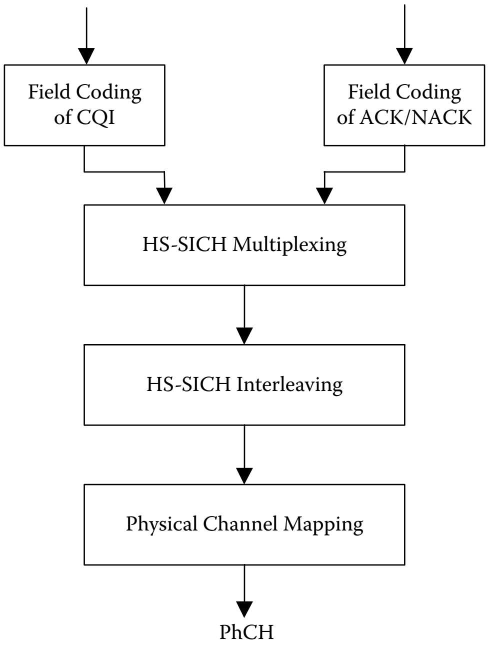

Figure 1.11 Physical layer processing for HS-SICH.

carry 44 information bits in the first data field and 40 information bits plus 2 bits TPC and 2 bits SS in the second data field, while HS-SCCH2 will be used to convey 88 information bits only (see Figure 1.12). The physical layer processing of HS-SCCH is shown in Figure 1.13.

The following information is transmitted on HS-SCCH:

1. Channelization code set information (8 bits). HS-PDSCH channelization codes are allocated contiguously from a signaled start code to a signaled stop code, and the allocation includes both the start and stop code. The start code is signaled by the first 4 bits (the code length is 16 chips) and the stop code by the remaining 4 bits.
2. Time slot information (5 bits). The time slots used for HS-PDSCH resources are signaled by the bits $x_1, x_2, \ldots, x_5$, where bit x_n carries

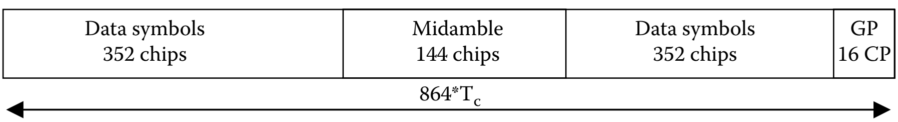

Figure 1.12 Burst type of HS-SCCH (T_c is the chip duration).

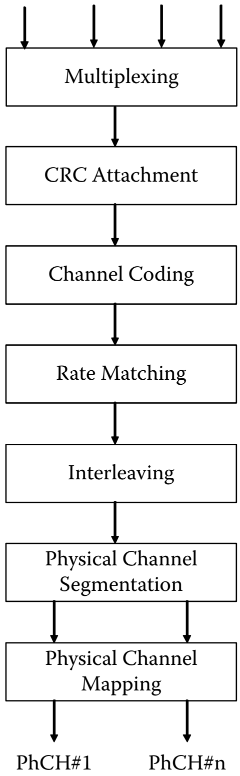

Figure 1.13 Physical layer processing for HS-SCCH.

the information for timeslot $n + 1$. Timeslots 0 (conveys common control channels, such as P-CCPCH) and 1 (always used for uplink) cannot be used for HS-DSCH resources. If the signaling bit is set (i.e., equal to 1), then the corresponding time slot is used for HS-PDSCH resources. Otherwise, the time slot is not used. All used time slots employ the same channelization code set, as signaled by channelization code set information bits.

3. Modulation scheme information (1 bit). The modulation scheme used by the HS-PDSCH resources is signaled by this bit, with the value 0 indicating QPSK and the value 1 indicating 16QAM.
4. Transport block size information (6 bits). The transport block size information is an unsigned binary representation of the transport block size index from 0 to 63.
5. Hybrid ARQ process information (3 bits). The hybrid-ARQ process information is an unsigned binary representation of the HARQ process identifier from 0 to 7.

Table 1.1 RV Mapping

	QPSK		*16QAM*		
X_{rv}	*s*	*r*	*s*	*r*	*b*
0	1	0	1	0	0
1	0	0	0	0	0
2	1	1	1	1	1
3	0	1	0	1	1
4	1	2	1	0	1
5	0	2	1	0	2
6	1	3	1	0	3
7	0	3	1	1	0

6. RV information (3 bits). The RV parameters r, s and the constellation version parameter b are mapped jointly to produce the value X_{rv}. This is done according to Table 1.1 according to the modulation mode used.

The other information conveyed on HS-SCCH includes new data indicator (1 bit), indicating whether or not the related HS-DSCH transmission is a new transmission; HS-SCCH cyclic sequence number (3 bits); and UE identity (16 bits).

1.4.5 HS-DSCH Operation Procedure

This section overviews the basic HS-DSCH operation procedures, including the link adaptation procedure, the channel quality reporting procedure, the HS-SCCH monitoring procedure, and the Iub interface flow control procedure. From these procedures, one obtains a general understanding of how the TD-SCDMA HSDPA system operates.

1.4.5.1 Link Adaptation

For HS-DSCH, the modulation scheme and effective code rate are selected by higher layers located within Node-B. This is achieved by appropriate selection of an HS-DSCH transport block size, modulation format, and resources by higher layers. If UE supports multi-carrier HS-DSCH reception, higher layers may select multiple carriers to transfer the data. Carrier selection may be based on CQI reports from the UE. If the UE supports multi-carrier HS-DSCH transmission, the UE will report the CQI information of

every carrier via HS-SICH. The overall HS-DSCH link adaptation procedure consists of the following two parts:

1. *Node-B procedure.* Node-B transmits HS-SCCH carrying a UE identity indicating the UE to which HS-DSCH TTI is to be granted. In the case of HS-DSCH transmissions in consecutive TTIs to the same UE, the same HS-SCCH is used for associated signaling. If UE supports multi-carrier HS-DSCH reception, the above HS-SCCH detection procedure is applied on each independent carrier. Node-B transmits HS-DSCH to the UE using the grant indicated in the HS-SCCH. Upon receiving the HS-SICH from the respective UE, the status report (ACK/NACK and CQI) is passed to higher layers.
2. *UE procedure.* When indicated by higher layers, the UE starts monitoring all HS-SCCHs that are in its HS-SCCH set. In the case that an HS-SCCH is identified as correct by its CRC, the UE reads the HS-PDSCHs indicated by the HS-SCCH. If UE supports multi-carrier HS-DSCH reception, UE may acquire HS-PDSCH resource allocation information of each carrier according to the associated HS-SCCHs. In the case that an HS-SCCH is identified to be incorrect, the UE will discard the data on the HS-SCCH and return to monitoring. After reading the HS-PDSCHs, the UE generates an ACK/NACK message and transmits this to Node-B in the associated HS-SICH, along with the most recently derived CQI. If UE supports multi-carrier HS-DSCH reception, the CQI and ACK/NACK of every carrier are transferred via individual HS-SICHs.

1.4.5.2 HS-DSCH Channel Quality Indication

The channel quality indicator (CQI) provides Node-B with an estimate of the code rate that would have maximized the single-transmission throughput of the previous HS-DSCH transmission if decoded in isolation. The CQI report must be referenced to a given set of HS-PDSCH resources by Node-B. The reference resources for a CQI report is a set of HS-PDSCH resources that were received by the UE in a single TTI and contain a complete transport block. These resources will be known to Node-B from the relative timings of the HS-SICH carrying the CQI and previous HS-DSCH transmissions to the UE.

As described above, the CQI consists of two fields: RTBS and RMF. The UE uses the same mapping table for these fields as is being used for the time slot information and modulation scheme information fields, respectively, of the HS-SCCH. The detailed reporting procedure is as follows:

1. The UE receives a message on an HS-SCCH telling it which resources have been allocated to it for the next associated HS-DSCH transmission.

2. The UE reads the associated HS-DSCH transmission and makes the necessary measurements to derive a CQI that it estimates would have given it the highest single-transmission throughput for the allocated resources while achieving a BLER (block error ratio) of no more than 10%. BLER is defined as the probability that a transport block transmitted using the RTBS and RMF is received in error if decoded in isolation. For the purposes of this calculation, it assumes that the transport block that would be transmitted with these parameters would use redundancy version parameters $s = 1$ and $r = 0$. Using this definition of BLER, single-transmission throughput can be defined as single-transmission throughput = $(1 - \text{BLER}) \times \text{RTBS}$.
3. The CQI report derived from a given HS-DSCH transmission is reported to Node-B in the next HS-SICH available to the UE following that HS-DSCH transmission, unless that HS-SICH immediately follows the last allocated HS-DSCH time slot, in which case the subsequent available HS-SICH is used by the UE. This HS-SICH may not necessarily be the same HS-SICH that carries the ACK/NACK information for that HS-DSCH transmission. The UE will always transmit the most recently derived CQI in any given HS-SICH.

1.4.6 HS-SCCH Monitoring

In a multi-frequency HS-DSCH cell, a UE divides its HS-SCCH set into one or more HS-SCCH subsets; in each HS-SCCH subset, all HS-SCCHs are associated with the same frequency's HS-PDSCH. When indicated by higher layers, the UE will start monitoring all HS-SCCHs in all HS-SCCH subsets to acquire the configuration information of HS-PDSCHs. In the case that one HS-SCCH is detected carrying its UE identity, the UE skips monitoring the remaining HS-SCCHs in this HS-SCCH subset, and restricts its monitoring to only previously detected HS-SCCH in the following TTIs. The UE sets all HS-SCCHs carrying its UE identity in all HS-SCCH subsets into an active set, and sets all HS-SCCH subsets in which no HS-SCCH carries its UE identity into a remaining set.

In the case that the multi-carrier number is not configured by higher layers, a UE will always monitor all HS-SCCH subsets. Otherwise, the UE may skip monitoring the remaining HS-SCCH subsets when the number of HS-SCCHs carrying its UE identity; that is, the number of HS-SCCHs in the active set is equal to the configured value.

During the following TTIs, the UE updates and maintains the active set and the remaining set. If one or more HS-SCCHs in the active set do not carry its UE identity, the UE removes them from the active set and sets their corresponding HS-SCCH subsets into the remaining set. Meanwhile, if one or more HS-SCCHs in the remaining sets are detected carrying its UE

identity, the UE sets these found HS-SCCHs into the active set and removes their corresponding HS-SCCH subsets from the remaining set.

1.4.6.1 Iub Flow Control Procedure

The HSDPA architecture splits the MAC layer between the RNC and Node-B. MAC PDUs generated by the RNC, called MAC-d PDUs, are aggregated and sent to Node-B over the Iub interface in HS-DSCH DATA FRAME. Node-B buffers the PDUs until they are scheduled and successfully transmitted over the air interface to a UE. The delivery of PDUs over the Iub is managed by a flow control protocol, which can act independently for each CmCHPI (common transport channel priority) of each UE.

Node-B is the master of the flow control. The whole procedure includes the transmissions of two control frames (HS-DSCH CAPACITY REQUEST FRAME and HS-DSCH CAPACITY ALLOCATION FRAME) and one data frame (HS-DSCH DATA FRAME). The HS-DSCH CAPACITY REQUEST FRAME is used for the RNC to request HS-DSCH capacity by indicating the user buffer size in the RNC for a given priority level. The RNC is allowed to reissue the HS-DSCH Capacity Request if no CAPACITY ALLOCATION has been received within an appropriate time threshold. The HS-DSCH CAPACITY ALLOCATION FRAME is used by Node-B to control the user data flow. In the CAPACITY ALLOCATION FRAME, HS-DSCH Credits IE (information entity) indicates the number of MAC-d PDUs that the RNC is allowed to transmit for the MAC-d flow and the associated priority level indicated by the CmCHPI Indicator IE, and the Maximum MAC-d PDU length, HS-DSCH Credits, HS-DSCH Interval, and HS-DSCH Repetition Period IEs indicate the total amount of capacity granted. Any capacity previously granted is replaced.

When the RNC has been granted capacity by Node-B via the HS-DSCH CAPACITY ALLOCATION FRAME or via the HS-DSCH initial capacity allocation and the RNC has data waiting to be sent, then the HS-DSCH DATA FRAME is used to transfer the data. If the RNC has been granted capacity by Node-B via the HS-DSCH initial capacity allocation, this capacity is valid for only the first HS-DSCH DATA FRAME transmission. When data is waiting to be transferred, and a CAPACITY ALLOCATION is received, a DATA FRAME will be transmitted immediately according to allocation received. Multiple MAC-d PDUs of the same length and same priority level (CmCHPI) may be transmitted in one MAC-d flow in the same HS-DSCH DATA FRAME. The HS-DSCH capacity allocation procedure is generated within Node-B. It may be generated either in response to an HS-DSCH capacity request or at any other time. Node-B can use this message to modify the capacity at any time, irrespective of the reported user buffer status. Figure 1.14 illustrates one possible use of the flow control messages. In the example, the first two allocation messages are unsolicited and are generated despite the user buffer size being zero.

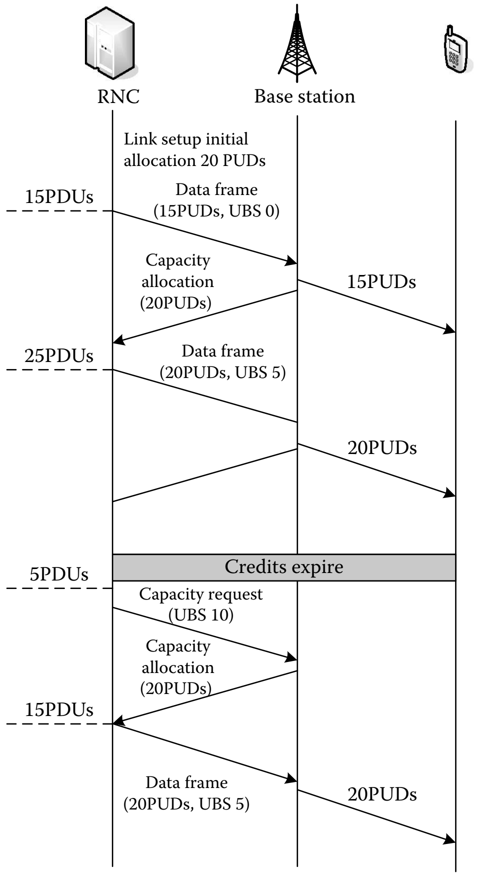

Figure 1.14 Example of Iub flow control procedure (UBS, user buffer size).

1.5 TD-SCDMA HSUPA

1.5.1 Concept and Principles

TD-SCDMA HSDPA focuses mainly on downlink improvement of TD-SCDMA systems. Limited uplink capacity is becoming a bottleneck. In 2007, the 3GPP finished the low chip rate TDD-HSUPA (i.e., TD-SCDMA HSUPA) specification, which is believed to be able to enhance the uplink TD-SCDMA networks significantly.

Due to the TDD nature, TD-SCDMA HSUPA is quite different from WCDMA HSUPA [22, 31]. WCDMA HSUPA is based on enhanced-dedicated channel (E-DCH). Hybrid ARQ and fast rate scheduling, which are located in the base station are used to enhance DCH performance. Rate scheduling is responsible for uplink interference resource (RoT [rise over thermal noise]

resource) scheduling. In TD-SCDMA HSUPA, the concept is mainly on the basis of shared channel. The scheduler, located in the base station, is in charge of both resource and rate scheduling, which is more like that done in TD-SCDMA HSDPA. Another difference is that higher modulation was adopted in TD-SCDMA HSUPA (i.e., 16QAM), while WCDMA HSUPA uses only QPSK modulation. Due to these essential differences, TD-SCDMA HSUPA has its specific characteristics in both the technique aspect and the protocol aspect. This section aims to dig out such essential differences and tries to present a "real" TD-SCDMA HSUPA from both the technique and protocol aspects. Also, this section presents the distinct resource management characteristic of TD-SCDMA HSUPA, and some useful conclusions are drawn.

TD-SCDMA HSUPA aims to enhance the uplink performance of TD-SCDMA networks. Due to the limited uplink channelization code resource, the scheduler, which is located in base station, is designed to manage not only the uplink interference resource (i.e., RoT resource), but also the code resource. In the performance evaluation section of this chapter, we show that due to the effect of interference suppression by smart antennas, the RoT resource control may not be as urgent as that in a WCDMA HSUPA system. Hybrid ARQ is adopted in TD-SCDMA HSUPA to allow for error correction in the physical layer, and less RLC layer ARQ is required in order to meet a certain quality, thus improving the overall end-to-end latency performance. Due to the gain brought by smart antennas and the power-saving nature inherent in TDD operation, high modulation has potential gain in TD-SCDMA HSUPA system. Close loop power control is used to overcome the near–far problem and facilitate the operation of transmission format combination (TFC) control. In the following of this section, we will introduce the general system architecture and channels that facilitate the operation of these features.

Figure 1.15 shows the system architecture of TD-SCDMA HSUPA on both the UE side and the UTRAN [Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access Network] side. The main modification of the TD-SCDMA HSUPA protocol stack with respect to a traditional TD-SCDMA system concerns the physical and MAC layers. For the UTRAN side, Hybrid ARQ soft combining is introduced in the physical layer to combine the information of different transmissions, which results in a higher successful decoding probability. MAC-e (enhanced) and MAC-es are newly added MAC sublayers. MAC-e, which is located in the base station, is in charge of uplink scheduling, rate control, transmission of scheduling grants, and the Hybrid ARQ related operation. Due to the Hybrid ARQ operation, the PDU arriving in the RLC (radio link control) layer may not be in sequence. MAC-es, which is located in the RNC, is responsible for MAC-es PDUs reordering. On that UE side, the MAC-e/es sublayer performs TFC selection and handles the Hybrid ARQ protocol-related functions.

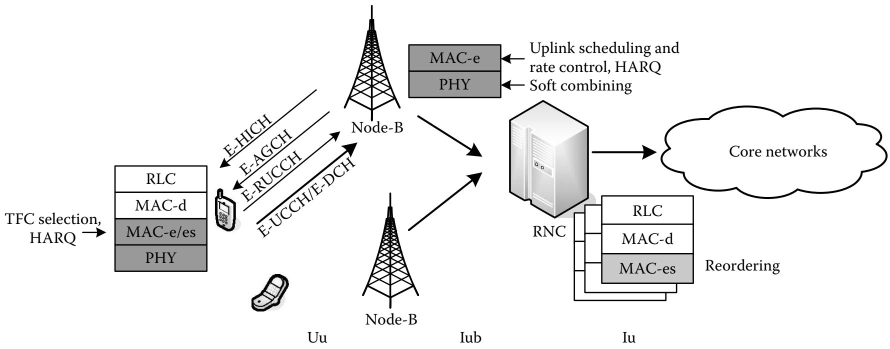

Figure 1.15 TD-SCDMA HSUPA system architecture.

TD-SCDMA HSUPA introduces one transport channel and four physical channels. The newly added transport channel is the E-DCH, which is used to transmit traffic data. Its physical layer channel is the E-DCH physical uplink channel (E-PUCH). The four physical channels are E-DCH random access uplink control channel (E-RUCCH), E-DCH absolute grant channel (E-AGCH), E-DCH uplink control channel (E-UCCH), and E-DCH Hybrid ARQ indicator channel (E-HICH). These four physical channels are used for control purposes. The E-RUCCH is used to carry Scheduling Information, such as the UE buffer status and power headroom, when E-PUCH resources are not available. The E-AGCH carries the UE-specific resource grant, which includes both code and interference resources. The grant information indicates the specific UE to transmit data using what physical resource and at what maximum allowable transmit power. The E-UCCH is the E-DCH associated channel, the function of which is the same as HS-SCCH in HSDPA. It indicates the TFC used in E-DCH and carries Hybrid ARQ process ID information The E-HICH is used to carry Hybrid ARQ acknowledgment sent from the base station. The transmission of Scheduling Information is necessary in the case of separate operation of the scheduling entity (i.e., base station in HSUPA) and data transmission entity (i.e., UE in HSUPA). The scheduling entity needs such information to make a reasonable judgment. When the UE has no resource to send traffic (i.e., no E-PUCH resource), it can initiate E-RUCCH transmission to inform the base station of such information. When the UE has an E-PUCH resource, the scheduling information is transmitted as a MAC-e header.

1.5.2 Key Techniques

1.5.2.1 Uplink Hybrid ARQ

The Hybrid ARQ in TD-SCDMA HSUPA utilizes the N-process ARQ protocol, which is the same as that in HSDPA. The ARQ used here operates in an

asynchronous way. The time between data transmission and its feedback is fixed, while the time between different transmissions is flexible and is determined by scheduling policy.

The Hybrid ARQ profile specified in TD-SCDMA HSUPA can provide MAC-layer QoS differential. The Hybrid ARQ profile includes the power offset and the maximum allowed transmissions. The power offset allows certain traffic to pump more power than what is typically needed. Higher power means lower probability of needing a retransmission and thus, low latency. These two attributes allow for flexible Hybrid ARQ operation. For example, delay-sensitive services can use a relative high power offset and low retransmission probability, while delay-tolerant traffic can have more transmissions and obtain more ET gain.

1.5.2.2 Power Control and TFC Selection

The near–far problem is inherited in CDMA uplink operation. Closed-loop power control is a well-known solution to settle such a problem. Different from WCDMA HSUPA, which is based on always-on-DPCCH for closed-loop power control, in TD-SCDMA HSUPA, the E-AGCH and E-PUCH is a closed-loop power control pair. The transmitting power of E-PUCH is determined according to the following formula:

$$P = P_{e\text{-}base} + L + \beta_e + K_{E\text{-}PUCH} \tag{1.1}$$

where L is the path-loss between the base station and UE, β_e is the gain factor and is specific for individual TFCs, $K_{E\text{ - }PUCH}$ is the Hybrid ARQ power offset, and $P_{e\text{-}base}$ is a closed-loop control component that is adjusted according to the TPC command carried on E-AGCH

$$P_{e\text{-}base} = PRX_{des\_base} + \eta \cdot \sum_i TPC_i \tag{1.2}$$

where $PRX_{des\text{-}base}$ is the required received reference power and η is the power adjusting step. Because the value of $P_{e\text{-}base}$ is known at both the base station and UE, the base station can effectively control the transmit power of certain UE in such a way that no extra code channel is required for maintaining the closed-loop power control, which is especially important for TD-SCDMA HSUPA for its relative lower chip rate.

TFC selection is performed at the UE MAC-e layer based on the transmitting power each TFC needs and the maximum transmitting power allowed by the network. TFC selection performs the same way as that in R99 DCH. In brief, the TFC requires the largest power, but not higher than the maximum power allowed by network. Because TD-SCDMA HSUPA adopts a higher modulation level (i.e., 16QAM), a separate gain factor list should be provided. In TD-SCDMA HSUPA, the base station controls the maximum allowed power that a certain UE can assume, and thus the network can effectively control the data rate at which UE may transmit. As mentioned

above, because power saving is inherited in TDD mode and smart antenna can provide potential high gain, a higher modulation level has potential gain in TD-SCDMA HSUPA, which will be shown later in the performance evaluation section.

1.5.2.3 Scheduling, Rate, and Resource Control

Scheduling, rate, and resource control are the main radio resource management functions in a packet services-oriented system. In TD-SCDMA HSUPA, the corresponding functional entity is the MAC-e located in the base station; it allows rapid resource allocation and exploiting the burstiness in packet data transmissions. It enables the system to admit a larger number of high data rate users and rapidly adapt to both interference and user channel variations, thereby leading to an increase in capacity as well as an increase in the likelihood that a user will experience high data rates.

The TD-SCDMA HSUPA uplink resource includes not only the tolerable interference (i.e., the maximum allowed received power at base station), but also the uplink code channel. For TD-SCDMA HSUPA, due to the use of smart antennas, things can be different. Uplink code channel scheduling should receive more attention than the interference resource control. As commonly known, smart antennas not only can boost the absolute signal strength but also have a positive effect on interference suppression. Besides, the joint detection used in uplink can eliminate a large part of the multiple access interference. The possible scenario that may results large interference between users is that the interfering users (UE2) are in the same direction as that of the victim user (UE1), which is shown in Figure 1.16.

Because TD-SCDMA HSUPA is based on sharing mechanism, the possibility of such a large interference scenario is somewhat low. Even when such a scenario occurs, Hybrid ARQ can further recover the former interference-corrupted packet, and the probability that the same scenario will also occur in the retransmission is very small.

TD-SCDMA HSUPA is code-limited in the uplink for its relative lower chip rate and adopting common scrambling code for all uplink transmissions. [30] Code channels (i.e., orthogonal variable spreading factor [OVSF] codes) should be carefully managed, and one should ensure that these limited codes can be efficiently utilized.

Just as for the downlink user and packet scheduling, the scheduling policy is an implementation issue and is flexible based on system requirements. The scheduling method may take user fairness, traffic priority, service QoS, and the operator's operating strategy into consideration. The fast responding ability to the interference and channel variation of scheduling enables the system to accommodate larger numbers of packet traffic users and can fully exploit the multi-user diversity gain.

The scheduling, rate, and resource control related framework includes two channels (E-RUCCH and E-AGCH) and the user status information,

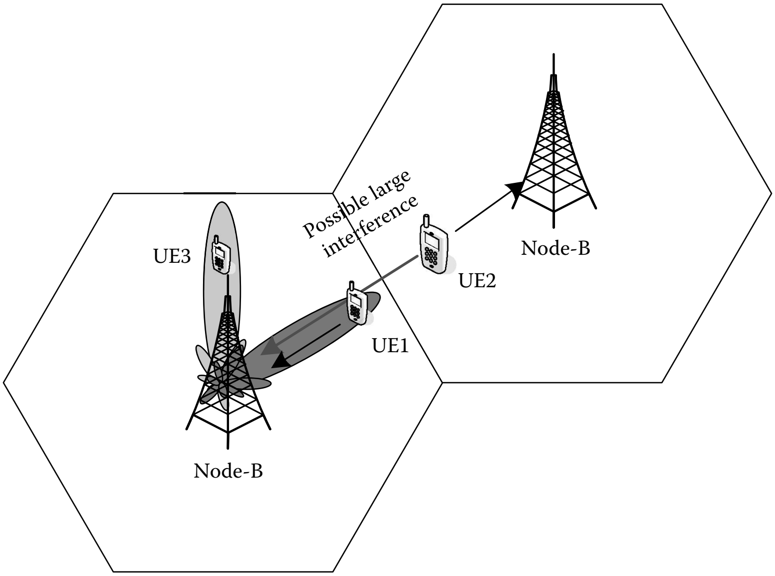

Figure 1.16 Interference scenario under smart antenna for TD-SCDMA HSUPA.

which is Scheduling Information. When a certain user has no uplink resource to transmit data, it initiates E-RUCCH transmission to report its Scheduling Information to networks. After the scheduling, rate, and resource control procedure, a judgment is made whether to allocate a resource to that user. If true, E-AGCH is transmitted to inform the user the uplink resource information, which includes time slot, code channel, and power resource and may be the duration of such allocation depend on whether this allocation is valid more than one TTI or not. If the allocation is valid more than one TTI, E-AGCH will carry the duration of the allocation. If not, T-AGCH will not contain the information. After decoding E-AGCH, the user will transmit data using the resource allocated by the network. Unlike WCDMA HSUPA, TD-SCDMA HSUPA does not employ soft handover. No other grant channel is transmitted besides E-AGCH. E-RGCH (E-DCH Relative Grant Channel) is another grant channel in WCDMA HSUPA besides E-AGCH, which is used mainly for interference control. Because interference control is not as urgent as in a WCDMA system, it is not necessary to adopt another channel for such a purpose in TD-SCDMA HSUPA.

In addition to the dynamic scheduling policy, TD-SCDMA HSUPA also allows non-scheduling transmission, which is especially suitable for serving the guaranteed bit rate services, such as VoIP. Such a mechanism allows users to transmit urgent data, such as delay-sensitive traffic data or signaling, without waiting for the base station's scheduling grant. It enables the QoS guarantee for some special traffic.

1.5.2.4 Multi-frequency Operation

For the relative low chip rate that TD-SCDMA HSUPA deploys, the peak data rate is 2.2 Mbps. It is relatively low compared to that of WCDMA HSUPA, which is 5.76 Mbps. Multi-frequency TD-SCDMA HSUPA is also specified. The basic operation principle is the same as that of multi-frequency TD-SCDMA HSDPA. The carrier data distribution is performed at the MAC layer below the MAC-es layer. Multi-frequency operation has potential gain inherited in frequency-selective gain.

1.5.3 TD-SCDMA HSUPA Channels

Similar to the TD-SCDMA HSDPA section, in what follows we first introduce the association and timing between the transport channel and control channel because it encompasses the basic operation requirements. Then we go into the details of channel processing for both transport channels and the related control channels.

1.5.3.1 Association and Timing

1.5.3.1.1 E-DCH and E-AGCH

The E-DCH is always associated with a number of E-AGCHs and up to four E-HICHs. A grant of E-DCH transmission resources may be transmitted to the UE on any one of the associated E-AGCHs. All relevant Layer-1 control information related in an E-DCH TTI is transmitted in the associated E-AGCH and E-HICH.

The E-DCH-related time slot information that is carried on the E-AGCH refers to the next valid E-PUCH allocation, which is given by the following limitation: There will be an offset of seven time slots between the E-AGCH carrying the E-DCH-related information and the first indicated E-PUCH (in time) for a given UE. DwPTS and UpPTS is not be taken into account in this limitation, as illustrated in Figure 1.17.

For semi-persistent E-DCH resources, the timing between E-AGCH and the first E-PUCH can be indicated by the information conveyed on E-AGCH. Once the semi-persistent resources are assigned to UE, the UE can use those resources continuously until the semi-persistent resources have been released or reconfigured by Node-B or RNC.

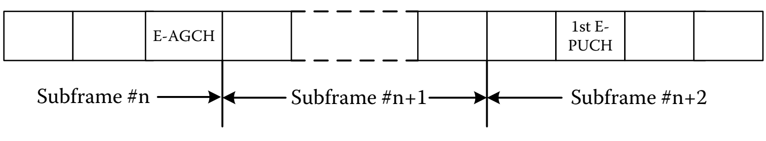

Figure 1.17 Timing for E-AGCH and E-PUCH (UpPTS and DwPTS not included).

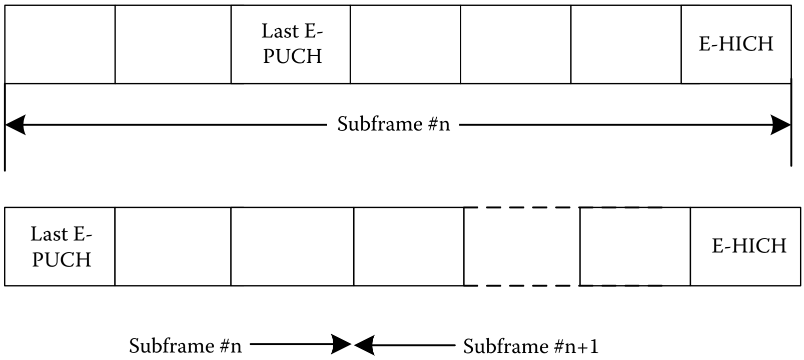

Figure 1.18 Timing for E-DCH and E-HICH (UpPTS and DwPTS not included).

1.5.3.1.2 E-DCH and E-HICH

For a given UE, an E-HICH is synchronously linked with the E-DCH TTI transmission to which it relates. The associated E-HICH resides on the first E-HICH instance of the E-HICH channelization code to occur after $n_{E\text{-}HICH}$ time slots have elapsed since the start of the last E-PUCH of the corresponding E-DCH TTI (see examples in Figure 1.18). The value of $n_{E\text{-}HICH}$ is configurable by higher layers within the range of four to fifteen timeslots, and DwPTS and UpPTS is not taken into account in this limitation.

1.5.3.2 Channel Processing

1.5.3.2.1 E-DCH

Figure 1.19 shows the processing structure for the E-DCH transport channel mapped onto a separate coded composite transport channel (CCTrCH). Data arrives at the coding unit in the form of a maximum of one transport block once every TTI. A TTI of 5 ms will be used, which is the same as the DL. As for HS-DSCH, a CRC length of 24 bits is attached to each transport block, and the rate 1/3 Turbo coding is used as channel coding for E-DCH. The Hybrid ARQ functionality matches the number of bits at the output of the channel coder to the total number of bits of the E-PUCH set to which the E-DCH transport channel is mapped. The Hybrid ARQ functionality is controlled by the RV parameters. Figure 1.20 shows the detailed processing of E-DCH Hybrid ARQ functionality. The parameters of the rate matching stage depend on the value of the RV parameters *s* and *r*. Similar to HS-DSCH, constellation rearrangement is performed in the case of 16QAM in accordance with the general method described for HS-DSCH. For QPSK, this function is transparent.

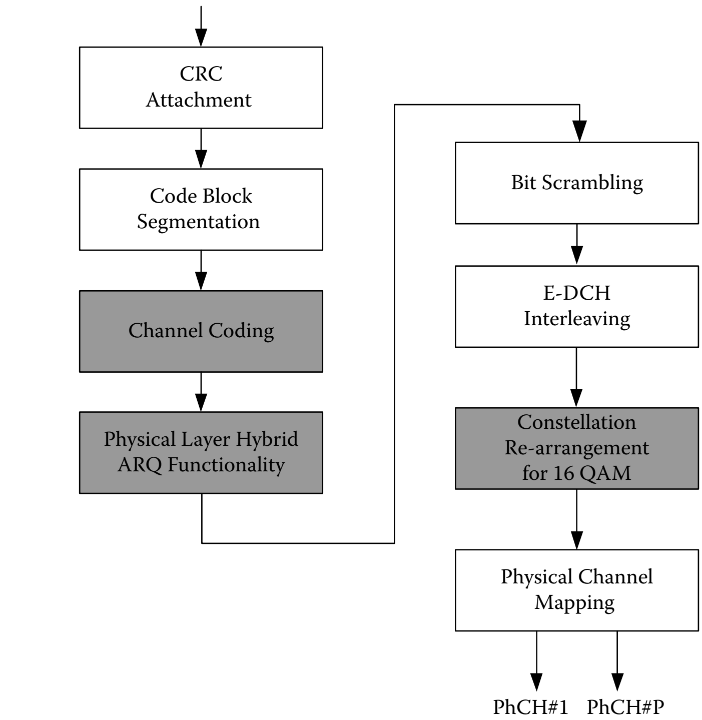

Figure 1.19 Physical layer processing for E-DCH.

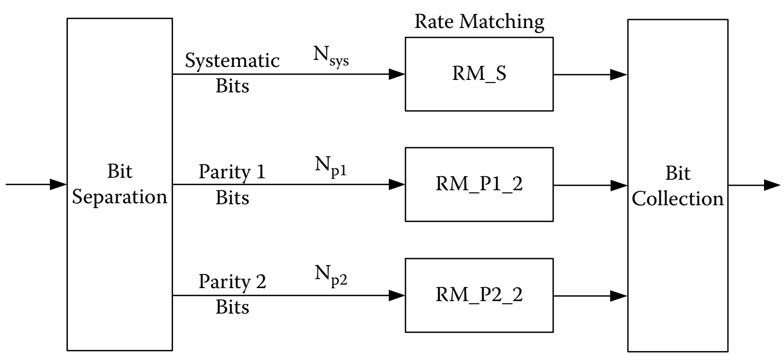

Figure 1.20 E-DCH Hybrid ARQ functionality.

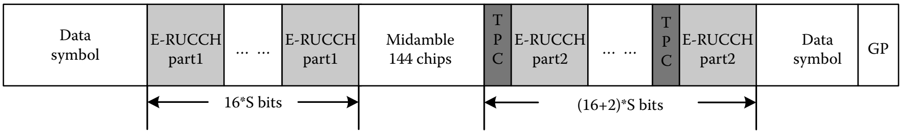

Figure 1.21 Multiplexing of E-DCH and E-UCCH (S is an indication of repetition level).

1.5.3.2.2 E-UCCH

The E-UCCH carries uplink control information associated with the E-DCH and is mapped to E-PUCH, which means that E-UCCH is multiplexed with E-DCH and mapped to the same physical channel. Depending on the configuration of the number of E-UCCH instances and the number of E-PUCH time slots, an E-PUCH burst may or may not contain E-UCCH and TPC. When E-PUCH does contain E-UCCH, TPC is also transmitted. When E-PUCH does not contain E-UCCH, TPC is not transmitted. For one E-UCCH instance, we have 32 physical channel bits, modulated using QPSK modulation. There is at least one E-UCCH and TPC in every E-DCH TTI. Multiple instances of the same E-UCCH information and TPC can be transmitted within an E-DCH TTI. The detailed number of instances can be set by the Node-B MAC-e layer for scheduled transmissions and signaled by higher layers for nonscheduled transmissions. When an E-DCH data block is transmitted on multiple time slots in one TTI, there will be multiple E-PUCH time slots. All repetitions of E-UCCH and TPC are evenly distributed on multiple E-PUCH time slots. The burst composition of the E-UCCH information and the E-DCH data is shown in Figure 1.21.

Figure 1.22 shows the E-PUCH data burst with and without the E-UCCH/TPC fields.

The E-UCCH is used to convey the following information:

- The modulation type of the selected E-TFC (0 bits)
- The transport block size of the selected E-TFC (6 bits)
- The retransmission sequence number (RSN) (2 bits)
- The HARQ process ID (2 bits)

Different from HS-DSCH, the occupied modulation type is not explicitly signaled (0 bits for this information), which is inferred from the transport

Figure 1.22 E-PUCH data burst without E-UCCH/TPC

Data symbol 352 chips	Midamble 144 chips	SS	T P C	Data symbol 352 chips	GP

Figure 1.23 E-AGCH1 burst structure.

block size. The same as HS-DSCH, there are total 64 kinds of transport block size (6 bits). Because it is the UE's responsibility to choose the transmitted TFC, which, combined with the granted resource, determines the block size, the UE informs Node-B of such information via these 6 bits.

To indicate the RV of each Hybrid ARQ transmission, a 2-bit RSN is signaled. Node-B can avoid soft buffer corruption by flushing the soft buffer associated to one Hybrid ARQ process in case the last received RSN for that Hybrid ARQ process is incompatible with the current one. For a given Hybrid ARQ process, once the maximum RSN value of 3 is reached, the RSN alternates between the values of 2 and 3 for any further retransmissions. The used RV and the constellation rearrangement parameter are implicitly linked to the transmitted RSN [14]; as such, the Node-B is always able to determine the correct RV and constellation rearrangement parameter if the RSN information is correctly obtained.

These 10 bits are then multiplexed and coded using a (32, 10) subcode of the second-order Reed-Muller code, which results in 32 bits for each E-UCCH instance.

1.5.3.2.3 E-AGCH

The E-AGCH is a downlink physical channel carrying the uplink E-DCH absolute grant control information. The E-AGCH uses two separate physical channels (E-AGCH1 and E-AGCH2). The spreading factor used for E-AGCH is 16. The burst structures for E-AGCH1 and E-AGCH2 are shown in Figure 1.23 and Figure 1.24, respectively. E-AGCH1 will carry the TPC and SS bits.

The E-AGCH carries the following fields multiplexed into 23 to 26 bits:

- *Absolute grant (power) value (5 bits).* This field indicates the granted power by the base station to specific UE for E-DCH transmission. This information can be used for uplink interference and load control purposes. There are a total of 32 different kinds of power grant levels.
- *Code resource related information (5 bits).* This field indicates the specific code resource grant for the E-DCH transmission.

Data symbol 352 chips	Midamble 144 chips	Data symbol 352 chips	GP

Figure 1.24 E-AGCH2 burst structure.

- *Timeslot resource related information (5 bits).* This field indicates the specific time slot resource grant for the E-DCH transmission, indicating the allocation for E-DCH resources from TS1 to TS5. If the bit is set (i.e., equal to 1), then the corresponding timeslot will be used for E-DCH resources.
- *E-AGCH cyclic sequence number (ECSN) (3 bits).*
- *Resource duration indicator (3 bits, if present).* This is used for semi-persistent scheduling, indicating the valid resource allocation duration.
- *E-HICH indicator (2 bits).* This is used to indicate the UE that E-HICH will use to convey the acknowledgment indicator in the following schedule period.
- *E-UCCH number indicator (3 bits).* This is used to calculate the number of E-UCCH instances.

Figure 1.25 illustrates the overall coding chain for the E-AGCH. After multiplexing the above information, a 16-bit CRC is calculated and attached

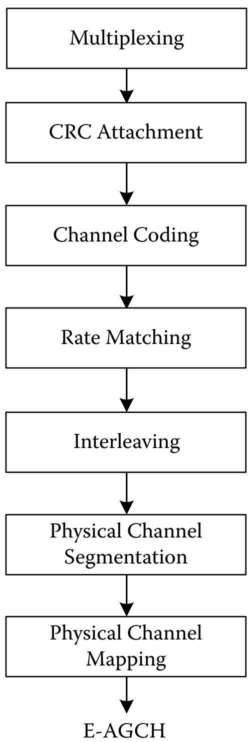

Figure 1.25 Physical layer processing for E-AGCH.

Figure 1.26 E-HICH structure.

to the sequence, and then a 1/3 rate convolutional channel coding is applied. After rate matching and interleaving, the sequence is segmented and mapped to the two physical code channels (E-AGCH1 and E-AGCH2).

1.5.3.2.4 E-HICH

The E-HICH is defined in terms of an SF16 downlink physical channel and a signature sequence. The E-HICH carries one or multiple users' acknowledgment indicator. Figure 1.26 illustrates the structure of the E-HICH. The spare bit values are undefined. The power of each user's acknowledgment indicator may be set independently by Node-B. The number of E-HICHs in a cell is configured by the system. Scheduled traffic's and non-scheduled traffic's acknowledgment indicators are transmitted on different E-HICHs. The acknowledgment indicators for the E-PUCH semi-persistent scheduling operation can be transmitted on the same E-HICH carrying indicators for scheduled traffic or on the E-HICH carrying indicators for non-scheduled traffic.

For scheduled transmissions, at most four E-HICHs can be configured for one user's scheduled transmission. Which E-HICH is used to convey the Hybrid ARQ acknowledgment indicator is indicated by the 2-bits E-HICH indicator on the E-AGCH. A single E-HICH can carry one or multiple Hybrid ARQ acknowledgment indicator(s), which are decided by the Node-B.

For non-scheduled transmissions, E-HICHs carry not only the HARQ acknowledgment indicators, but also TPC and SS commands. The 80 signature sequences are divided into 20 groups, and each group includes four sequences. Every non-scheduled user is assigned only one group. Among the four sequences, the first one is used to indicate ACK/NACK, and the other three are used to indicate the TPC/SS commands.

For E-DCH semi-persistent scheduling, E-HICHs carry not only the HARQ acknowledgment indicators, but also the TPC and SS commands. Each user is also assigned one signature sequence group, including four sequences whose usage is completely compliant with the definition in non-scheduled transmissions.

Detailed coding and multiplexing of E-HICH is not introduced here due to space limitations. One can refer to [14] for more detailed information. In general, because TD-SCDMA HSUPA supports various uplink transmission modes (i.e., scheduled, non-scheduled, and semi-persistent scheduled), the coding and multiplexing of E-HICH is different for different transmission modes.

1.5.3.2.5 E-RUCCH

The E-RUCCH is used to carry E-DCH associated uplink control signaling when E-PUCH resources are not available, for example, at the beginning of the data transmission. It is mapped to the same random access physical resources defined by UTRAN. It uses spreading factor SF = 16 or SF = 8. The set of admissible spreading codes used on the E-RUCCH is based on the spreading codes of PRACH. The time slot format depends on the spreading factor of the E-RUCCH. In general, no TPC and SS bits are transmitted.

1.6 Performance Evaluations

From the above sections, one can obtain a general understanding of the principles, technologies, and concepts of TD-SCDMA HSDPA/HSUPA. In this section, we provide performance evaluations for certain key aspects of TD-SCDMA HSDPA/HSUPA, including the performance benefits of the key techniques, the system average throughput in a typical macro-environment, etc. The performance results given here are intended to provide readers with further understanding of the capabilities of TD-SCDMA HSDPA/HSUPA. Readers can refer to [28–30] for more performance evaluations results: for example, the performance of different beamforming algorithms in [28], the performance of different detection methods in [29], and the performance of VoIP [30].

For the performance evaluation, a dynamic system level simulator was developed [32]. This simulator is based on OPNET Modeler® software with the assistance of link level simulation by the actual value interface (AVI). The simulation scenario is a typical Macro 19 cells with 3 sectors in each cell. The wrap-around technique is used to eliminate the boundary effect. The inter-site distance is 1 km. The propagation model, including path loss and shadow fading, is based on the UMTS 30.03 specification. The channel model is Pedestrian-A and the user mobility is 3 km/h.

In the simulator, key techniques of TD-SCDMA HSDPA/HSUPA, such as adaptive smart antenna, power control, HARQ for UL and DL, UL and DL scheduling and resource control, are all implemented. For UL, closed-loop power control is implemented according to Equations (1.1) and (1.2), and the power control step is 0.5 dB. In the simulation, in order to get enough position samples, 25 users are randomly distributed in each sector. A full buffer traffic model is used, and Proportional Fairness (PF) scheduling is used to calculate user priority. If not explicitly stated, Hybrid ARQ with a maximum of four transmissions is enabled. Note that valuations are separately performed for DL and UL, that is, concurrent UL and DL traffic transmissions are not simulated. The results provided mainly focus on the UL because for TD-SCDMA, UL is the bottleneck link.

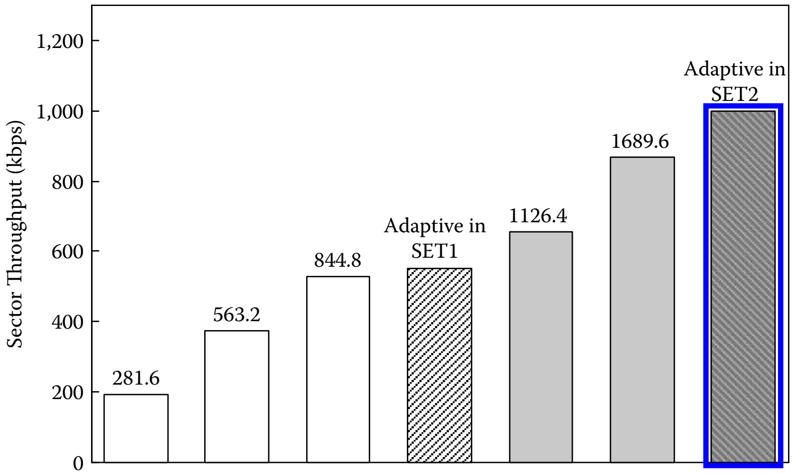

Figure 1.27 Sector throughput comparison of different TFCs.

1.6.1 Higher Modulation Level Gain

Figure 1.27 shows the sector throughput comparison of different TFC sets for UL. TFC SET1 means the data rate of {70.4, 140.8, 211.2} kbps using one time slot, while SET2 is {70.4, 140.8, 211.2, 281.6, 422.4} kbps, and adaptive in SET1 and SET2 means that TFC selection can be performed adaptively among such sets. The other bars mean only use the corresponding TFCs. The latter two TFCs in SET2 (i.e., 281.6 and 422.4 kbps) use 16QAM to pump more bits. In the simulation, four uplink traffic time slots are assumed. This boosts the TFC rate value to four times, which is shown above each bar in the figure. We can see that a higher modulation level has potential gain. From the throughput point of view, adaptive selection in SET2 gains 80.6% over that only in SET1. Although, in real network scenarios, the gain may not be as high due to the channel estimation error and beamforming error, the potential gain still can be obtained. It can also be seen that allowing for the selection of TFC freely among all TFCs is always better than sticking to just one. From these results, one can see the performance of high modulation and also the gain brought about by freely choosing among multiple modulation and coding sets.

1.6.1.1 Hybrid ARQ

To observe Hybrid ARQ related performance, Dynamic TFC selection is disabled in the simulation and a rate of 140.8 kbps is assumed (for a total of four time slots, the rate is 563.2 kbps). Figure 1.28 shows the normalized sector throughput with different maximum allowed transmissions.

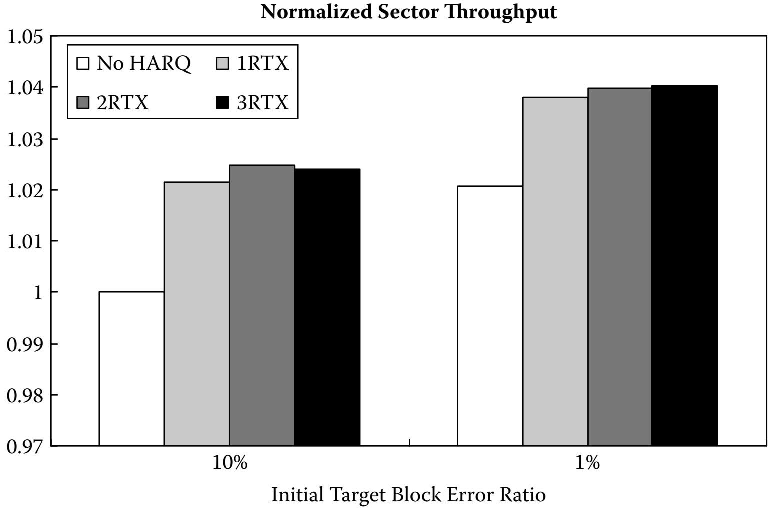

Figure 1.28 Sector throughput under different Hybrid ARQ operation scenarios.

The target block error ratio of initial transmission is set to 10% and 1%. It can be seen that Hybrid ARQ can bring significant gain concerning the system throughput while the contribution of the first retransmission is the most. The succeeding retransmissions can reduce the system's overall error ratio with little improvement from a throughput point of view. Good trade-off should be made between the overall system error ratio requirement and the air interface resource usage efficiency. Targeting a lower error ratio improves the overall system throughput but more transmit power is required.

Figures 1.29 and 1.30 show the ET gain of Hybrid ARQ operation. Two operating methods are adopted and compared. In the first method, TFC with the rate of 422.4 kbps is used and we aiming at three times of transmissions to achieve the 10% BLER target. In a second method, TFC with the rate of 140.8 kbps is adopted but only one transmission is allowed to achieve the same BLER target. Consequently, the overall target rate is 140.8 kbps. The first method aims at three transmissions, while the second aims at only one transmission to achieve such a rate. Figure 1.29 shows the sector throughput for the two methods, while Figure 1.30 shows the successful decoding probability of each transmission and also the residual BLER. It can be seen that the first method, which has a higher target error ratio for each transmission, also has more chance to retransmit to achieve the same overall error ratio and gets much better performance than the second method.

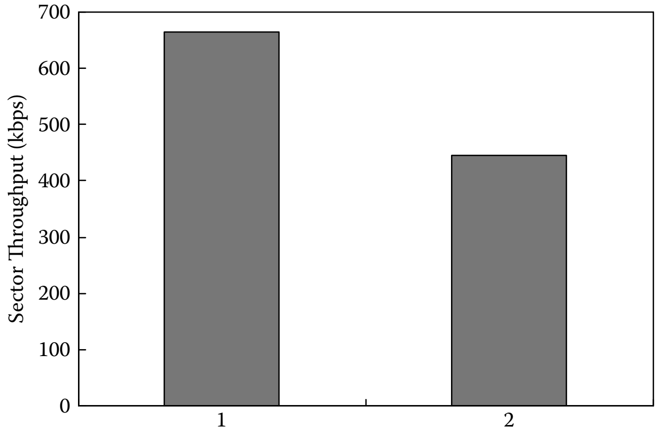

Figure 1.29 Throughput of the different schemes.

1.6.2 Interference Distribution and Control

Figure 1.31 and Figure 1.32 show the PDF (probability density function) and CDF (cumulative distribution function) curves of RoT value in UL under smart antenna and directional antenna, respectively. The smart antenna used here is 60° sector smart antenna, and the pattern is collected from trial networks. The directional antenna is a typical 120° sector directional antenna. In the simulation, no power grant is sent; that is, the maximum allowed transmitting power the user can adopt is the maximum power that the user can support. It can be seen that most of the RoT value under a

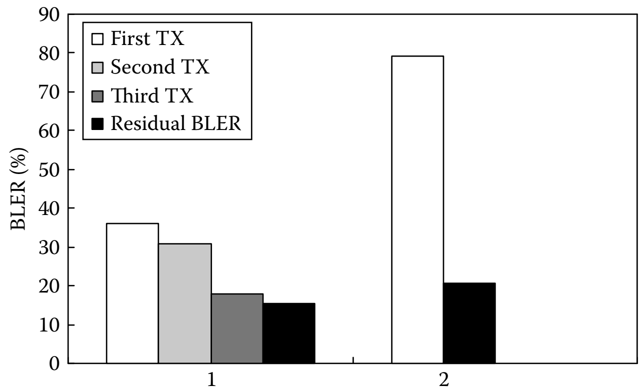

Figure 1.30 Successful transmission probability of each transmission and the residual BLER.

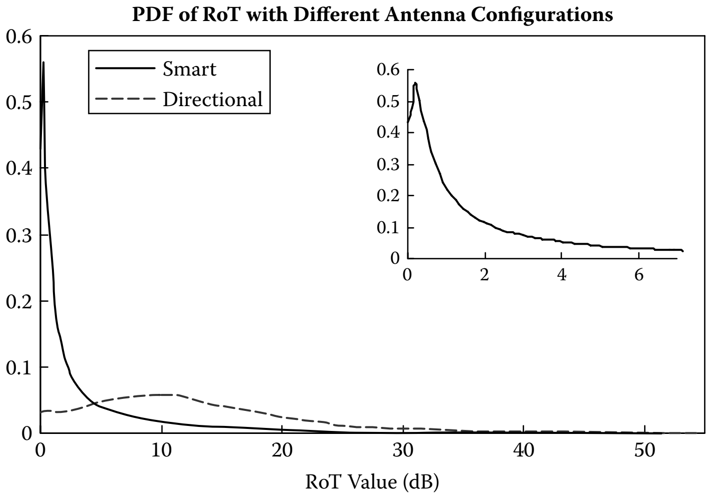

Figure 1.31 Probability density function (PDF) of RoT.

smart antenna is very small compared to that under a directional antenna. The mean RoT value under smart antennas is 3.65 dB while it is 11.93 dB under directional antennas. The overshot probability, which is defined as the RoT value higher than 7 dB, is 16%. This is mainly due to the scenario mentioned in the above section. Such overshot probability does have a negative impact on the user's data, but it is relatively difficult to avoid for the independent scheduling procedure performed in each cell. Fortunately,

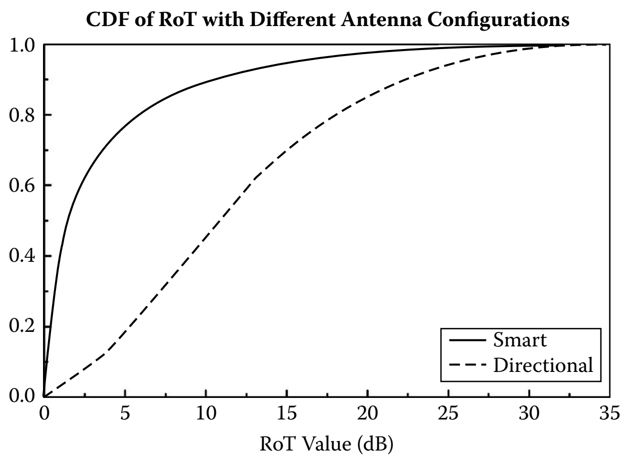

Figure 1.32 Cumulative density function (CDF) of RoT.

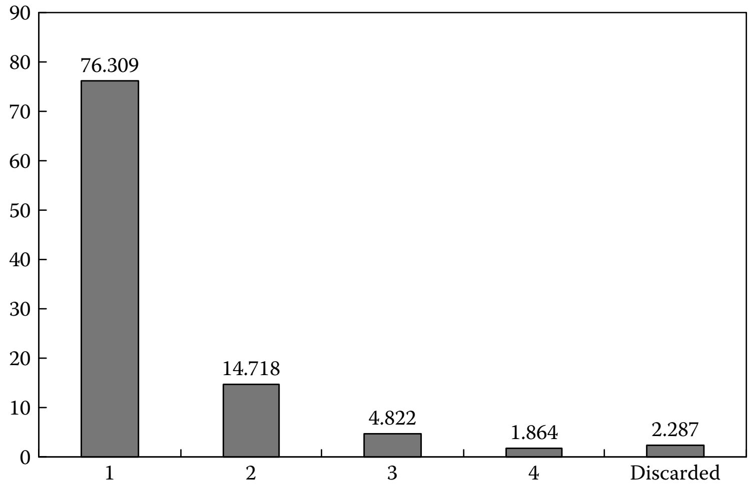

Figure 1.33 Successful transmission probability of each transmission and residual BLER.

however, we have Hybrid ARQ to help us cope with such a bad situation. The residual BLER after certain retransmissions can be very low. Figure 1.33 shows the successful transmission probability of each transmission and also the residual BLER. The initial transmission target BLER is 10%. That means that we aim to get about 90% of the packets transmitted successfully at the initial transmission. But due to the severe interference scenario mentioned above, such a target is somewhat hard to achieve. Only 76.3% of the packets are successfully transmitted at the initial transmission. About 24% of the packets encounter such a scenario and also heavy fading during the initial transmission. Here, Hybrid ARQ is an attractive way to solve the problem. After the first retransmission, another 14.72% of the packets are successfully decoded. That is to say, after the first retransmission, the overall percentage of incorrect packets is only 8.97% (1 − 76.3% − 14.72%). If we take the overshot probability by RoT higher than 7 dB as judgment for the heavy interference scenario, most of the 16% of the packets which interference by such heavy interference scenario is successfully recovered by Hybrid ARQ first retransmission (24% − 8.97% = 15.03%).

1.6.3 Multi-frequency Operation

One unique characteristic for TD-SCDMA HSPA is its multi-frequency operation. In what follows, the potential gain brought by multi-frequency is demonstrated. As we know, the basic benefit brought about by multi-frequency operation is the enhancement of transmission capability. The single-link peak data rate can be boosted to K (the number of frequencies

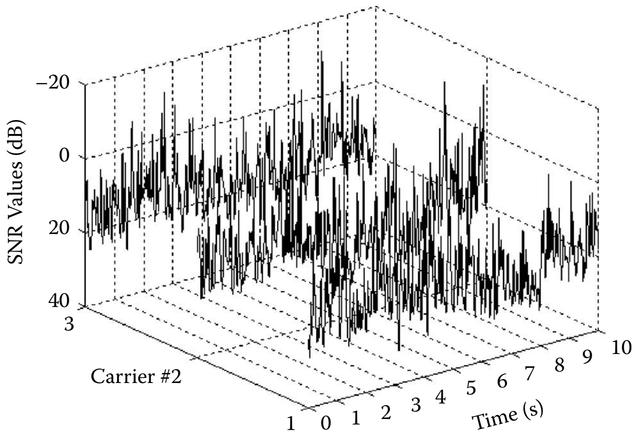

Figure 1.34 Received SNR plot.

adopted) times compared to single-frequency operation. Because the occupied frequency band is also K times, no improvement in the spectral efficiency is observed (there is even loss due to the guard band). However, for multi-user operation, the spectral efficiency can be improved due to the multi-user diversity gain (MUD). MUD in single-carrier TD-SCDMA HSPA can be exploited by serving users at or near their channel peaks, while multi-frequency TD-SCDMA HSPA provides additional multi-user diversity gain in the frequency domain. This indicates the potential higher spectral efficiency over single carrier for multi-user operation. In the frequency domain, multi-user diversity gain comes from the different fading characteristics across carriers. It is the function of inter-carrier channel correlation. High channel correlation reduces the independence of signal paths, thus limiting the diversity gain. The frequency domain channel correlation can be described by coherence bandwidth f_c, which is the reciprocal of the delay spread. Typically, f_c is hundreds of kilohertz (kHz), which is far less than the single-carrier bandwidth of multi-frequency TD-SCDMA HSPA. Thus, sufficient channel de-correlation can be achieved, which results in the possible exploitation of multi-user diversity gain in the frequency domain. Figure 1.34 plots the received SNR of one user observed from three carriers simultaneously in the DL. It can be seen that there exists adequate fading in both the time and the frequency domains that can be used to exploit multi-user diversity gain in both domains.

For exploiting such gain, the design of user and packet scheduling methods is of great importance. The following three scheduling methods are considered in the evaluations. These methods are the possible modifications of the well-known PF scheduler to multi-frequency operation.

1. *Multi-carrier integrated scheduling (MC-IS).* In MC-IS, all carriers' resources are combined into one resource block. Scheduling and resource allocation are performed on this integrated block. At each scheduling time t, MC-IS allocates all carriers' resources to UE j if

$$j = \arg\max {r_i(t)}/{\bar{R}_i(t)} \tag{1.3}$$

where $r_i(t)$ is the sum of instantaneous supporting rate of user i on all K carriers at time t:

$$r_i(t) = \sum_{k=0}^{K-1} r_{ik}(t) \tag{1.4}$$

$r_{ik}(t)$ is the instantaneous supporting rate of user i on carrier k. $\bar{R}_i(t)$ is the window averaged rate of user i achieved on all carriers:

$$\bar{R}_i(t) = (1 - 1/t_c) \cdot \bar{R}_i\,(t-1) + 1/t_c \cdot \sum_{k=0}^{K-1} r_{ik}(t) \tag{1.5}$$

where t_c is the time filter constant. If the user has not been served on carrier k at time t, then, we have $r_{ik}(t) = 0$.

2. *Multi-carrier separately scheduling (MC-SS).* MC-SS schedules carriers one by one. The scheduler allocates the resource of carrier k to UE j_k if

$$j_k = \arg\max {r_{ik}(t)}/{\bar{R}_{ik}(t)} \tag{1.6}$$

$\bar{R}_{ik}(t)$is the averaged rate of user i got on carrier k:

$$\bar{R}_{ik}(t) = (1 - 1/t_c) \cdot \bar{R}_{ik}\,(t-1) + 1/t_c \cdot r_{ik}(t) \tag{1.7}$$

3. *Multi-carrier independence scheduling (MC-IDS).* At time t, MC-IDS allocates the carrier k resource to the UE j_k if

$$j_k = \arg\max {r_{ik}(t)}/{R_i(t)} \tag{1.8}$$

Figures 1.35 through 1.37 show the sector DL throughput and residual BLER performance of both single-frequency and multi-frequency systems under the considered scheduling schemes. It can be seen that the throughput of the multi-frequency system is much higher than that than of the single frequency system for the additional frequency resources. System throughput under MC-SS is exactly three times that of single-frequency with PF scheduling. Because of the additional multi-user diversity gain exploited by MC-IDS in the frequency domain, system throughput under

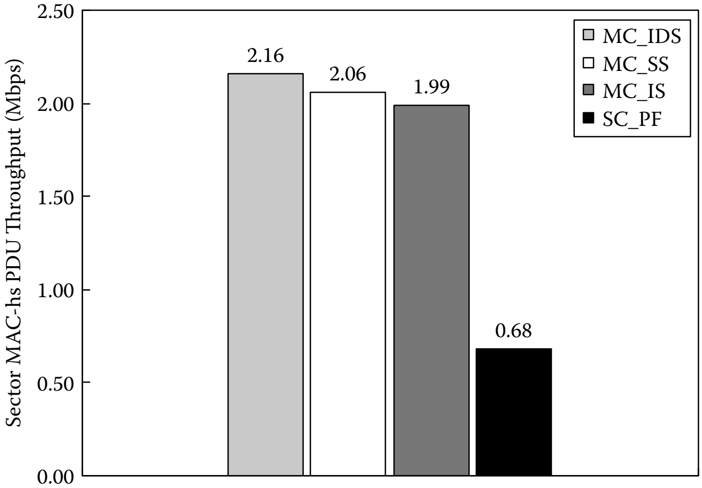

Figure 1.35 Sector MAC-hs PDU throughput for different schedulers.

MC-IDS is higher than that of MC-SS. When it comes to normalized throughput, MC-IDS gains 5.88% (0.228 dB) over MC-SS and also single-frequency with PF scheduling. Due to the impairment to multi-user diversity gain in both the time and frequency domains mentioned above, systems with MC-IS scheduling achieve the lowest throughput performance. The normalized throughput under MC-IS is even lower than single frequency with

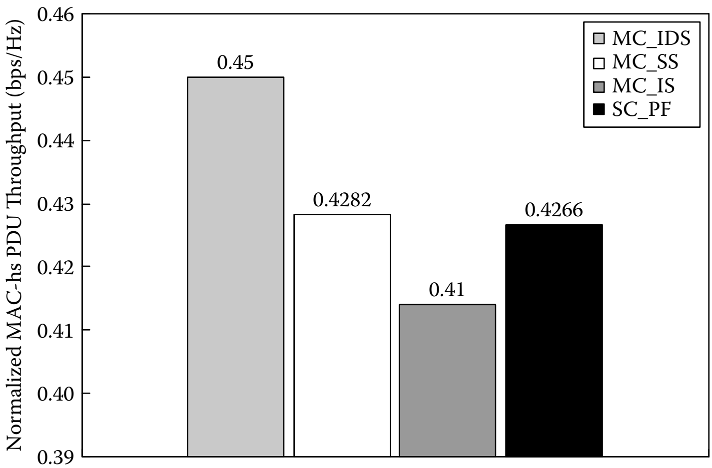

Figure 1.36 Normalized MAC-hs PDU throughput for different schedulers.

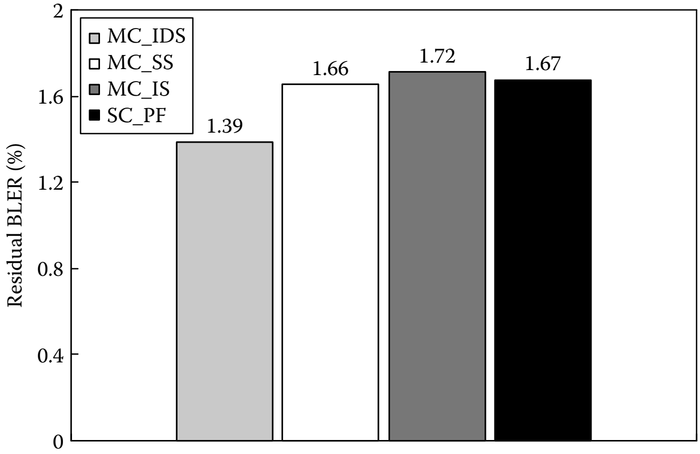

Figure 1.37 Residual block error ratio for different schedulers.

PF scheduling. Performance of system residual BLER is of the same trend as system throughput. Systems with MC-IDS achieve the lowest residual BLER performance and then the MC-SS, which is almost the same as SC-PF; the system residual BLER under MC-IS is the highest.

The higher system spectral efficiency under MC-IDS should also bring benefit to user experience. Figure 1.38 shows the complementary cumulative distribution function (CCDF) of user throughput. The curve labeled

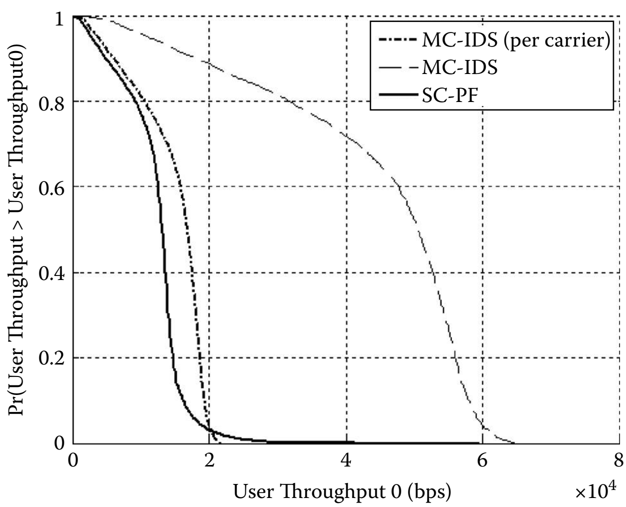

Figure 1.38 CCDF of user throughput.

"MC-IDS (per carrier)" is the CCDF of user throughput averaged per carrier in a multi-frequency system. It can be seen that users achieve more than three times the data rate in a three-frequency system as in a single-frequency system due to the additional diversity gain. The benefit for very high data rate users is limited and it increases for lower data rate users.

1.7 Summary

As the basic 3G choice in China, TD-SCDMA has been well developed and has been operated by the CMCC, one of the biggest operators in China. With the ever-increasing demand for higher data rates and the aim of providing various multimedia services, TD-SCDMA networks have evolved toward their enhanced version, TD-SCDMA HSDPA/HSUPA. This chapter provided an overview of this enhanced version, including the key techniques, channel processing, operation principles, and also some performance evaluations. The characteristics introduced here were based mainly on the 3GPP R5 and R6 versions. After these, some advanced techniques and operation options have been further absorbed into TD-SCDMA HSDPA/HSUPA, including MIMO operation, VoIP service, and 64QAM in DL, etc. With these features, TD-SCDMA HSDPA/HSUPA is believed to be able to provide various multimedia services, including file downloading and uploading, Web-surfing, e-mail, games, and VoIP, etc.

Acknowledgment

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Links

3GPP homepage. http://www.3gpp.org/
CCSA homepage. http://www.ccsa.org.cn/english/
TD-SCDMA forum. http://www.td-forum.org/en/

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